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Electrical Strength Analysis of SF6 Gas Circuit Breaker Element

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Abstract

This paper addresses the problems, connected with calculation of the electric field and analysis of surface flashover of node tank SF6 circuit breaker. Namely, the gap between the grounded tank unit, a filter system and a conductive system is receiving input power. The paper also provides the recommendations for change SF6 circuit breaker design.

Keywords: SF6 circuit breaker; discharge; gas gap; surface flashover, electric strength.

1. Introduction

SF6 circuit breaker insulation system design can be of two kinds with gas gap or along the surfaces of solid dielectrics. The discharge conditions of along the surfaces of solid dielectrics differ significantly from the discharge conditions in the gas gap and it can be the main factor in determining the circuit breaker geometric dimensions. In operation, the insulation system must withstand the normalized AC voltage and normalized overvoltages.

Nowadays SF_6 insulation has gained wide-spread acceptance in high-voltage units as internal insulation due to high physical-chemical and electrical characteristics. Therefore the demand arose for reliable and accurate calculation techniques for analysis of structures' electric strength by main gaps. However, presently available criteria are frequently empirical or semi-empirical and application – specific, consequently their application is limited [1]. Therefore performance evaluation of construction under high-voltage is complicated.

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2. Problem definition and solution

The discharge mechanism along the dielectric surfaces is still the subject of intense research [2, 3, 4] but theoretical description suitable for engineering calculations is currently unavailable. Therefore it is necessary to use different kind of simplification [5].

Based on presently-available calculation techniques, electric strength analysis of switching unit node under high voltage with internal insulation was performed in the present study. General view of switching unit node is given in Fig. 1 [6]. Nodes are numerated as follows: 1 - grounded casing; 2 - epoxy insulator; 3 - SF_6 cleanup system (filter); 4- clamping element for current conductor 7 and insulator 2; 5 - screen in current-conducting system-filter gap; 6 - screen in current-conducting system-grounded casing gap; 7 - current conductor. Gas flow is indicated by arrows.

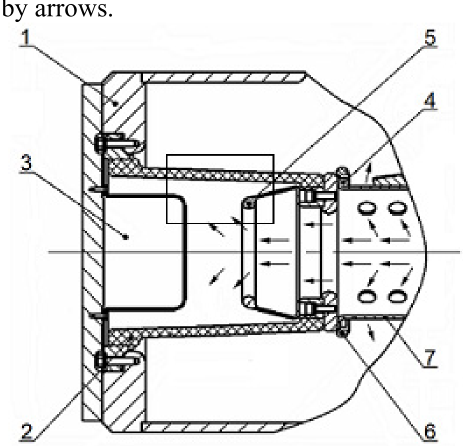

Fig.1. Node of high-voltage SF6 unit

Nominal voltage is 220 kV, SF6 inflation pressure (absolute) is 0,7 MPa.

The objective of the present study was to determine potential causes of insulator 2 flashover by internal and in some cases by external surface, during tests by normalized lightning pulses, particularly, to eliminate possible construction defects.

2.1 Calculation techniques

Distribution pattern of electrical field in the node under investigation (Fig. 2) was obtained for analytical calculation in software package Elcut 5.5 (corresponding region is denoted in Fig. 1 by rectangular frame). Herewith axially-symmetrical problem of electrostatics was solved. Field distribution is denoted by equipotential lines, intensity distribution is denoted by arrows. Elements designations are given in accordance with Fig. 1. Contours (a-b) and (c-d-e-f) indicate possible directions of discharge formation.

Axially-symmetrical problem setting slightly impairs calculation accuracy (in comparison with three-dimensional model), but it allows to carry out an estimative analysis. The most probable directions of discharge formation, subject to calculation, are given in Fig. 2. Basic parameters of gaps, under investigation, are given in Table 1. Two main gaps types can be distinguished in construction under investigation: purely gas-insulated gap (a-b, c-d, e-f) and a gap along insulator surface (d-e).

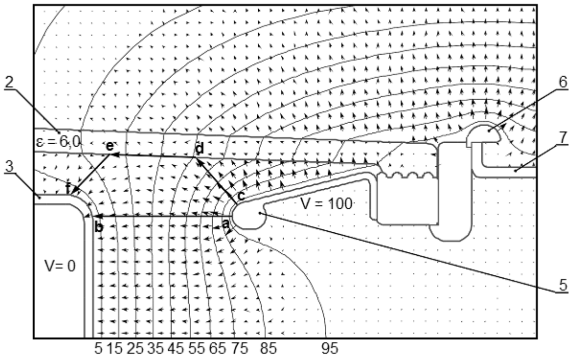

Fig.2. Model and calculation results of electrical field under applied voltage 100 kV.

2.2 Purely gas-insulated gaps

In general, calculation technique of purely gas-insulated gaps comprises:

- Definition of discharge independence condition in case of streamer or avalanche-type mechanism of discharge formation;
- Definition of analytical dependence of intensity distribution in a gap (in case of inhomogeneous fields);
- Definition of resultant expression for calculation of initial voltage with the use of approximated dependency of effective impact ionization coefficient on electrical field intensity.

Table 1. Basic parameters of gaps under investigation

Gaps	a-b	c-d	d-e	e-f
Medium	SF_6	SF_6	Along dielectric surface in SF_6	SF_6
Gap length	82,7	41,3	46,0	29,9
Field capacity factor	0,35	0,39	0,78	0,62
Loss in voltage on the gap	100	57,5	22,4	20,1

Discharge independence condition was applied as follows:

$$\int_0^{L_{cr}} \alpha_{eff} dl = K$$

where α_{eff} – effective impact ionization coefficient; L_{cr} – critical length of field force line, wherein $\alpha_{eff} = 0$; $K = 10,5$ [7, 11].

Distribution of field intensity in all gaps was approximated by the present dependence:

$$E = \frac{E_m}{(\frac{l}{R}+1)^2}$$

In accordance with [2], where E_m – intensity on the electrode surface, kV/mm; R – effective radius of sphere electrode, mm.

For calculated gap a-b more accurate approximation by the present expression was applied:

$$E = \frac{E_1}{(\frac{l}{l_{01}}+1)^{m_1}} + \frac{E_2}{(\frac{d-l}{l_{02}}+1)^{m_2}}$$

In accordance with [8, 9], where field intensity values on the electrodes surface are:

$$E_{m1} = \frac{E_1}{(\frac{l}{l_{01}}+1)^{m_1}} + E_2;\ E_{m2} = \frac{E_2}{(\frac{l}{l_{02}}+1)^{m_2}} + E_1.$$

In the last equation l is coordinate along force line of point under investigation, mm; l_0 - characteristic dimension, mm (spherical radius of screen 5 and filter 3 were accepted as characteristic dimensions); d – force line length, mm; field intensity $E = [kV/mm]$. Resultant expression for discharge voltage for the first case, considering linear approximation of dependence of effective impact ionization coefficient on electrical field intensity, is:

$$U_{BR} = (\frac{E}{p})_{cr}\, p \cdot (1 + \frac{k}{\sqrt{Rp}}) \cdot \zeta \cdot d \qquad (1)$$

where $(E/p)_{cr} = 89\, kV/(mm \cdot MPa)$ – critical value of reduced intensity, wherein $\alpha_{eff} = 0$; $k = 0{,}175\,(mm \cdot MPa)^{0{,}5}$ [10].

Analytical expression for the second case is not given in this article because of its awkwardness.

2.3 Gap along epoxy insulator surface

For calculation of electrical strength of a gap along epoxy insulator d-e the following empirical dependence was applied [11]:

$$U_{BR} = K \cdot P^{0{,}6} (\zeta \cdot d)^{0{,}8} \qquad (2)$$

where P - SF6 pressure, atm.; ζ – field capacity factor; d – gap length, cm.

Calculated values of electrical strength of gaps under investigation are given in Table 2.

Table 2. Calculation results

Gap	Calculated value of discharge voltage U_{BR} ,kV	Normalized lightning pulse value, kV
a-b	907,6 (1)	900
a-b	911,8	900
c-d	507,4	900
d-e	695,8	900
e-f	583,9	900

Obtained results show that there is an adequate electrical strength of construction in case of “pure” conditions in a gap, for which given expressions are correct. We can also make conclusion that approximated dependence of more simple form for intensity distribution in a gap in case of excessively inhomogeneous fields can be applied. Difference in calculated values is approximately 3%.

The results obtained indicate insufficient dielectric strength design, even for a gap in the unpolluted particles and decomposition products in SF6. The gas gap dielectric strength a-b is slightly greater than the withstand test voltage. Discharge voltage along the surface of the solid dielectric d-e is 0.77 of the withstand test voltage. Possible discharge path c-d-e-f is represented of electric line of force in the investigated gap, however, as shown in [5] the discharge gap along the surface of the dielectric may have another way.

Thus there is a high probability of electrical discharge occurrence in the gap either a-b or c-d-e-f.

3. Conclusion

In this paper, based on the discharge streamer inception criterion of tank circuit breaker electric strength is calculated. The results obtained indicate insufficient dielectric strength of this design. The theoretical results obtained during the lightning impulse test of breaker insulation are confirmed experimentally. At the moment, dielectric strength by varying the gap from 82 to 100 mm is increased.

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